CONSTRAINED INPUT-OUTPUT SIMULATIONS OF ENERGY RESTRICTIONS IN THE FOOD AND FIBER SYSTEM

J. B. Penn and George D. Irwin

Economic Research Service
U.S. Department of Agriculture

Agricultural Economic Report No. 280

CONSTRAINED INPUT-OUTPUT SIMULATIONS OF ENERGY RESTRICTIONS IN THE FOOD AND FIBER SYSTEM. By J. B. Penn and George D. Irwin. National Economic Analysis Divison, Economic Research Service. Agricultural Economic Report No. 280.

ABSTRACT

The energy shortages of the recent past have prompted a keen awareness of the pervasiveness of direct and indirect energy utilization in the domestic economy. Analysis of the relationship of energy to various components of the economic system requires treatment of the components in a total economic setting. Since the United States has a consistent set of national income accounts and their production account transforms into a sectoral input-output (I/O) tableau, I/O techniques appear to be a feasible way of incorporating this interrelatedness. The model utilized in this study is the readily available I/O construct incorporated into a linear programming framework and appended with BTU energy requirements and employment and value-added data. The impacts of energy resource shortages are explored for a representation of the food and fiber system in the context of sector interdependence.

KEYWORDS: Food and fiber system; I/O; linear programming; energy utilization; agricultural and food policy.

Washington, D.C. 20250 February 1977

CONTENTS

Page

Summary ii

Introduction 1

Conceptual Framework 1
  Model Components 1
    Input-Output Data 2
    Energy Requirements 2
    Employment and Product 2
  The Model 3
  Components 3

Situations Simulated 5
Simulation Results 5
  Base Solution 5
  Reduction of Crude Petroleum Imports 6
  Impact of Refined Petroleum Shortage 6
  Refined Petroleum Restriction, Alternative Objective Functions 7
  Natural Gas Restriction 8
  Expanding Agricultural Exports 8
  Impacts on a Food and Fiber System 9
  Shadow Prices 11

Model Credibility, Limitations, and Extensions 13
  Credibility 13
  Limitations 13
  Extensions 13

Conclusions 14

References 14

SUMMARY

The indirect or "hidden" effects of energy shortages and allocation schemes within the United States may produce economic impacts far different than might be presumed. Further, alternative allocation schemes could produce similar results for the entire economy yet have very different effects on individual sectors, such as agriculture. Additionally, fuel allocation schemes for agriculture—guaranteeing 100 percent of fuel needs, for example—may not help much if other needed inputs cannot be obtained.

Such schemes may work for a while. But as time elapses, other inputs could become scarce, making fuel no longer the most limiting production resource. The U.S. food and fiber system is vulnerable at several points to shortrun bottlenecks of needed inputs if delivery of energy supplies is interrupted.

These conclusions stem from four simulations processed through a constrained input-output (I/O) model that integrates I/O and mathematical programming techniques. Specific simulations in this model, which was used to study effects of alternate energy availabilities on the U.S. food and fiber system, were: (1) reduction of crude petroleum imports; (2) a shortage of refined petroleum; (3) restricted natural gas supplies; and (4) energy requirements for expanded agricultural exports. Effects on the U.S. economy were also examined, as were the economic impacts and tradeoffs of emphasizing one national objective over another.

Analysis of resource shortages can be improved by accounting for sectoral interdependence, a feature of the model. Such a model can provide information and flexibility needed in policy analyses. The model could be improved by expansions, refinements, and more current I/O data.

GLOSSARY OF ABBREVIATIONS

I/O	Input-Output
LP	Linear Programming
BTU	British Thermal Unit
GNP	Gross National Product
EC	Employee Compensation
PCE	Personal Consumption Expenditures
USDC	U.S. Department of Commerce
IBT	Indirect Business Taxes
PTI	Property-Type Income
TVA	Total Value Added
GDO	Gross Domestic Output
RHS	Right-hand Side
EMPL	Employment
FD	Final Demand

CONSTRAINED INPUT-OUTPUT SIMULATIONS OF ENERGY RESTRICTIONS IN THE FOOD AND FIBER SYSTEM

By

J. B. Penn and George D. Irwin[1]

INTRODUCTION

The energy shortages of the recent past have prompted a keen awareness that energy is essential to our existence—in direct form and embodied in the other necessities of life—food, clothing, and shelter. We have only recently begun to comprehend the complexity of energy transfers and usage throughout the economy. Interdependence arising from energy flows is far greater than had been widely recognized. Energy flows are not concentrated in one sector, industry, or firm, as past economic analyses have often been, and, further, most energy is consumed not as final product but as an intermediate product of the economy. Analysis of the relationship of energy to various components of the economic system requires treatment of the components in the context of the total economic setting of which they are a part.

The growing interdependence of all sectors of the national economy mandates more inclusive economic analyses than the traditional micro and partial equilibrium macro approaches provide. Since the U. S. Department of Commerce (USDC) maintains a consistent set of national income accounts and their production account transforms into a sectoral input-output (I/O) tableau, I/O techniques appear to be a feasible way of incorporating this interrelatedness. However, many of the problems of the food and fiber system, especially those involving primary resource shortages, require information beyond that available from standard I/O analyses.

The integration of I/O analyses and mathematical programming techniques into a constrained I/O model can provide much information not available from separate application of either technique (recent examples are (*13*) and (*17*)).[2]

This analysis uses a constrained I/O model to study effects of alternative energy availabilities in the food and fiber system, in the context of the national economy. More specifically, the readily available I/O construct is incorporated into a linear programming (LP) framework in order to examine impacts of energy resource shortages in the context of sector interdependence. The following sections will describe and discuss the model utilized, estimates and interpretation from an illustrative set of simulations, and finally, limitations, credibility, and extensions of the model.

CONCEPTUAL FRAMEWORK

Our approach permits us to examine energy impacts on many variables of interest: levels of individual sector output, final demands, employment, Gross National Product (GNP), and energy utilization. We can also identify bottlenecks arising from possible energy contingencies, which would not be evident from national aggregate supply-demand balances. Further, this approach allows introduction of primary resource constraints and the evaluation of allocation schemes through resulting shadow prices (dual multipliers) available from the LP algorithm.

Model Components

The framework for this analysis is based upon an optimizing model composed of three basic components:

[1]At the time of writing, Penn and Irwin were agricultural economists in the National Economic Analysis Division of the Economic Research Service (ERS), stationed in the Department of Economics and Business, North Carolina State University, Raleigh, North Carolina. Penn is now leader of the Agricultural Policy Analysis Program Area, Commodity Economics Division, ERS, and Irwin is Director of Research, Farm Credit Administration. The authors wish to acknowledge the contributions of B. A. McCarl and L. Brink to this report and of John H. Berry for his facilitating support of the project.

[2] Italicized numbers in parentheses refer to items in References at the end of this report.

(1) The national I/O tableau; (2) data on direct energy requirements; and (3) employment and value added data.

Input-Output Data. The I/O data are available from the national income accounts of the USDC (*21*) in three forms: (1) gross dollar flows, in producer prices, moving between sectors; (2) direct requirements from other sectors per dollar of output of a sector; and (3) total requirements (direct and indirect) of a sector from each other sector per dollar of output. Indirect requirements occur because a direct requirement from a second industry usually requires it, in turn, to initiate purchases from a third industry, and so forth. The matrix of direct requirements was the most convenient for constructing the LP model discussed here.

The I/O portion of the model was partially closed by internalizing the "household" sector—adding a row vector representing employee compensation (EC) and a column vector representing personal consumption expenditures (PCE). The "household" sector was included because of the emphasis on interdependence among sectors. It was reasoned that a higher degree of realism would be achieved by permitting the chain of induced effects on income, demand, and employment from energy changes by making this sector endogenous. This introduces a particular form of consumption function having a constant equal to nonwage personal income and a constant marginal propensity to consume.[3]

Energy Requirements. Direct BTU requirements per dollar of sales for each sector are included for coal, crude petroleum, refined petroleum, electricity, and natural gas (*6*, *18*).[4]

Total utilization of energy in BTU's required in 1967 is used as a base level (table 1) and any smaller amount is assumed to be a constraint on output.

Employment and Product. Other data included from the I/O tableau are indirect business taxes (IBT), property-type income (PTI), and total value added (TVA). Total gross product is obtained as a simple summation across sectors; that is, a unit vector is included. Also included as a separate measure of impacts are data on private employment per sector (unpublished data obtained from the Bureau of Labor Statistics).

[3]The constant arises from the inequality between PCE and EC; it accounts for income not arising from labor services so that the "household" row and column balance as required for entry into the endogenous portion of the model. Closing the model and adopting some of the USDC accounting conventions for use in our particular LP model formulation required modification of several sectors of the national accounts. These involved special handling of sector 80 (gross imports) to avoid double counting, sector 87 (inventory valuation adjustment), and the negative final demands (RHS) which resulted from the extraction of PCE from total exogenous final demand. Also, other special modifications are included in (*15*).

[4]These data were originally developed consistent with the USDC I/O tableau at the Center for Advanced Computation, University of Illinois for other purposes (*20*). Their availability for this study was a fortuitous circumstance for us and a serendipitious research payoff to society from research expenditures originally aimed in a quite different direction. Following USDC accounting conventions, extraction of crude petroleum and gas is first assigned to sector 8; crude petroleum is transferred (sold), primarily to the refining sector (31); and natural gas is sold to the gas utilities sector (68) within the I/O framework. Products of the coal mining (7) and refining sectors are sold directly to other sectors, and electricity, created from primary energy sources, is sold through the electric utilities sector. (In the 85-sector tableau, sector 68 is a composite of electric, gas, water, and sanitary service utilities but it is disaggregated to three separate sectors in the 367-sector tableau).

Table 1.—Aggregate U.S. energy balance, value and volume, 1967

Item	Coal	Crude petroleum and natural gas	Refined petroleum	Electricity[1]	Natural gas[1]
			Million dollars		
Domestic production					
Value					
Capacity	3,163	15,031	26,975	37,321	37,321
Actual	3,163	15,031	26,975	37,321	37,321
			10^{12} BTU's		
Volume					
Capacity	14,715.5	39,348.5	25,337.7	4,059.3	18,018.3
Actual	14,715.5	39,348.5	25,337.7	4,059.3	18,018.3
Imports					
Available	5.9	3,255.0	3,374.9	0.0	456.2
Utilization	5.9	3,255.0	3,374.9	0.0	456.2
Total					
Available	14,721.4	42,603.5	28,712.6	4,059.3	18,474.5
Utilization	14,721.4	42,603.5	28,712.6	4,059.3	18,474.5

[1] Electric and gas utilities are combined in the 85-sector tableau.

Source: Derived from (*20*) and (*21*).

The Model

The integrated I/O-LP model structure incorporating the components described above is expressed symbolically in matrix notation as follows:

$$
\begin{array}{llllll}
\text{Maximize} & X & & & & \\
\text{subject to} & (I-A)X-IY & & = & O & (1) \\
& IY & & \leqslant & FD & (2) \\
& LY- \; Y_o & & = & O & (3) \\
& E_1X \quad +E_2Y_o-P_1Z-P_2Z_o & & = & O & (4) \\
& P_1Z & & \leqslant & D & (5) \\
& P_2Z_o & & \leqslant & M & (6) \\
& HY & & \leqslant & O & (7) \\
& RX & & \leqslant & T & (8)
\end{array}
$$

Where:

- X is an 88 × 1 vector of sector gross outputs.
- A is an 88 × 88 matrix of coefficients of direct requirements per dollar of output.
- I is an 88 × 88 identity matrix.
- Y is an 88 × 88 diagonal matrix of exogenous final demands.
- FD is an 88 × 1 vector of upper limits on final demands.
- Y_o is the total final demand accepted by the economy.
- L is a unit vector to sum component final demands.
- E_1 is a 5 × 88 matrix of direct energy requirements (BTU's per dollar of output) for 5 energy types.
- E_2 is a 5 × 1 vector of direct energy requirements (BTU's per dollar of final demand).
- P_1, P_2 are 5 × 5 matrices of production and imports (BTU's per dollar of output) of the energy sectors.
- D is a 5 × 1 vector of domestically produced energy (BTU's) available by type.
- M is a 5 × 1 vector of imported energy (BTU's) available by type.
- Z, Z_o are vectors of domestic energy production and import activities for each energy type.
- H is a 2 × 88 vector of transportation and sales margins. This is used to convert from producer to purchaser prices for goods destined for final demand.
- R is a 5 × 88 matrix of sectoral employment, value added, and gross output data.
- T is a 5 × 1 vector of employment, value added, and gross output data totals.

Constraint (1) is the product balance. It is derived from the condition that sector output must be equivalent to the sum of its uses as intermediate products by other sectors and as final demand by the exogenous sectors; that is, $X = AX + Y$. The exogenous sectors are gross private fixed capital formation, net inventory change, net exports, and Federal, State, and local government purchases. The second constraint (2) is the demand balance. It limits the level of total exogenous final demand to a specified upper limit (in this case, the 1967 levels for the exogenous sectors when no primary resource constraints are effective). The RHS entry for the household row is nonwage personal income, which acts as a constant in the consumption function. Constraint (3) ensures equality of total final demand with the sum of its parts. Constraint (4) limits the use of energy by production and total final demand to no more than that available from domestic production and imports. Constraint (5) limits domestic production to no more than available production capacity. Constraint (6) limits maximum imports to the base solution quantities. Constraint (7) converts final demands from producer to purchaser prices. This is accomplished internally for intermediate products and domestic consumption. Constraint (8) simply accumulates employment, PTI, IBT, GDO, and GNP.

In this representation, gross output is maximized; however, other criterion functions may be selected (discussed more fully below). In particular, any of the constraints in (8) could be used as an objective. The model in schematic detail is shown in table 2.

Components

Rows and columns

- 1-88 (I-A) matrix including the "household" sector (EC and PCE).
- 89-176 Final demand constraints and activities which allow variable final demand levels and impose an upper limit.
- 177-177 A balance row and column charging direct energy requirements to be allocated among activities 89-176.

Rows

- 178-182 Direct BTU energy requirements per dollar of sector output and final demand balanced against production and imports.
- 183-187 Domestic energy production constrained to production capacity (defined as 1967 production levels).
- 188-192 Imports (limited to 1967 availability).
- 193-197 Production of energy (BTU's) by the energy sectors linked to dollar value of I/O energy activities.
- 198-199 Actual per dollar transportation and trade margins on final demand balance conversion from producer to purchaser prices.
- 200-204 Alternative criterion functions and accounting rows—employment (jobs) per sector, IBT, PTI, TVA, and gross domestic output (GDO).

Columns

- 178-187 Domestic and imported energy activities.
- 188 Vector of RHS values. The first 88 are null from constraint (1), 89-176 contain sector final demand upper limits, 177 is null, 178-182 are null, 183-187 are total domestic production capacity, 188-192 are potential imports, 193-199 are null, and 200-204 are base level limits.

Table 2.—Schematic of model

Rows	1 ... 88	89 ... 176	177	178 ... 182	183 ... 187		188
1 ... 88	(I-A) PCE EC	-1 -1 . . -1		BTU energy activities Production	BTU energy activities Imports	= . . . =	0 . . . 0
89 ... 176						$\leq$ . . . $\leq$	Final demand
177	Balance row	111 ... 111	-1			=	0
178 ... 182	Direct BTU/$ Output		BTU per $ FD	-a -a -a -a -a	-a -a -a -a -a	= . . . =	0 . . . 0
183 ... 187				+a +a +a +a +a		$\leq$ . . $\leq$	Domestic-energy production capacity
188 ... 192					+a +a +a +a +a	$\leq$ . . . $\leq$	Imports available
193 ... 197	-1 in energy producing activities only			1 1 1 1 1	1 1 1 1 1	= . . . =	0 0
198 199		Trade and transportation margin				= =	0 0
200 ... 204	Employment IBT PTI TVA Gross output						Base levels

SITUATIONS SIMULATED

To illustrate the types of questions that may be treated using the model, several simulations of alternative energy availabilities were obtained.[5] Aggregated results for 12 sets of simulations, as well as detailed results for 4 of these, are presented. The simulations presented are:

A. 1967 benchmark. This duplicates the actual data for 1967 in an LP solution to verify the programming formulation and to provide a reference for solution comparisons. Exact total energy requirements are also derived from this solution for validation against actual use.

B. Crude petroleum. Simulations of crude petroleum import reductions of 1.0 million (B-1) and 1.5 (B-2) million barrels per day were obtained using GDO as the criterion function. These reductions are 65 and 100 percent, respectively, of the 1967 import level.[6] These simulations are suggestive of the administration's energy strategy enunciated in January 1975 (*19*).

C. Refined petroleum. Refined petroleum products are reduced by an amount equivalent to 1 million barrels per day. The amount of this reduction was 6.96 percent below the 1967 use of 29.0 quadrillion BTU's. Specific simulations of this import restriction are:

   1. No allocation. This solution allows all sectors to compete freely for the reduced supply of refined petroleum.
   2. Allocation to government sector. We assume public sector final demands (which use most of the fuels required directly by final demand) must be met. This is done by making row 119 (the final demand for sector 31, petroleum refining) an equality.
   3. Allocation to government and farm production sectors. Full allocation is made to government final demand (as in 2 above) and the agriculture related sectors (1-4). This latter allocation is accomplished by zeroing BTU requirements per dollar of output for these sectors and subtracting their base level utilization from the total energy available for allocation (in the RHS).

D. Alternative objective functions. These simulations assume the same refined petroleum shortfall and the same allocation as in simulation (C-3) above. They examine the effects on problem solution of choice of a single national economic goal of maximizing four different objective functions: (1) Private employment;[7] (2) IBT; (3) PTI; and (4) total value added (GNP).

E. Natural gas restriction. This simulation reflects the situation suggested as possible for the East Coast and other areas during the winter of 1975-76, although it did not occur. The natural gas supply is reduced 10 percent, from 18.6 to 16.7 quadrillion BTU's, to estimate impacts of shortages of this energy source, which is particularly important for household consumption, fertilizer production, and certain manufacturing processes.

F. Expanded agricultural exports. This simulation examines the impact that a greatly expanded crop export level, such as that of 1974, would have had on the economy and on energy requirements. The export component of final demand for sector 2 (major agricultural crops) is tripled over the base year level and the solution obtained with two alternate levels of energy: (1) 1967 base and (2) an unconstrained total energy availability.

SIMULATION RESULTS

The patterns in the solutions for these 12 situations are presented in tables 3 and 4. A large amount of additional detail available from the model output is not shown. The 85 sectors have been aggregated into nine major groupings. We report only their output and final demand levels, along with levels for the seven aggregate indicators. We also define a food and fiber system and examine in more detail the variations in the output of individual sectors within the system and the pattern of final demands which go unmet when energy shortages occur.

Base Solution

The model was able to reproduce exactly the 1967 base levels of the U.S. economy (solution A) with a GDO of $1.52 trillion (*21*). This solution justifies confidence in the LP model formulation. It suggests that the data are at least properly entered and that the model is free from rounding error, despite a wide range in magnitude of individual coefficients. (The latter is not a trivial concern and

[5]Computations were performed on the IBM 370/365 Computer at the Triangle Universities Computing Center, Research Triangle Park, N.C., using the MPS/360 V2-M11 Math Programming Code.

[6]BTU reductions for crude petroleum were calculated using a conversion factor of 5.8 million BTU's per 42-gallon barrel. Reductions in refined petroleum products were calculated using a conversion factor of 5.47 million BTU's per barrel.

[7]Private employment includes wage and salary employees and self-employed and unpaid family workers; general Federal, State, and local government and private household employment are excluded.

Table 3.—Effect of simulations of alternative energy restrictions on base output of aggregated sectors, U.S. economy

Item	Sector numbers	Gross output base	Simulation B-1	B-2	C-1	C-2	C-3	D-1	D-2	D-3	D-4	E-1	F-1	F-2
		Mil. dol.	*Percent*											
Sector output:														
Agriculture, forestry, and fisheries	1-4	63,793	[1]97.2	94.3	97.5	90.2	88.6	92.2	88.2	93.9	87.1	94.6	112.2	112.4
Mining	5-10	24,959	93.3	90.9	93.7	94.6	91.1	91.1	89.8	90.6	91.3	89.4	97.9	98.7
Construction	11-12	103,281	94.5	93.3	94.9	97.7	98.7	98.6	88.2	93.2	98.7	98.4	98.5	99.9
Manufacturing	13-64	617,366	95.9	93.7	96.3	96.7	93.8	93.6	91.8	90.3	93.7	90.1	100.0	100.5
Transportation and communication services	65-68	112,657	95.8	93.4	96.2	95.8	93.2	93.1	93.1	92.2	93.3	91.8	100.1	99.2
Wholesale and retail trade	69	163,365	96.3	93.4	96.6	95.3	92.5	92.2	93.8	92.6	92.7	93.2	100.2	100.5
Finance, insurance, and real estate	70-71	161.005	96.6	93.6	96.9	95.1	91.8	91.5	93.6	92.9	92.0	93.5	98.7	98.3
Services	72-77	150,156	96.4	93.6	96.7	95.6	92.5	94.2	93.8	114.3	92.8	93.5	100.2	100.4
Other	78-86	123,934	101.8	101.0	100.4	100.3	99.4	92.2	97.9	99.1	98.4	100.6	99.7	99.2
Aggregate economic indicators:														
Personal consumption expenditures		490,660	96.7	93.3	97.0	94.8	91.2	90.6	94.1	93.0	91.4	93.8	100.0	100.3
Indirect business taxes		70,239	96.2	93.4	96.6	95.3	92.3	92.2	93.3	92.6	92.4	93.1	99.9	99.8
Property-type income		257,745	96.2	93.7	96.6	95.4	92.6	90.9	92.3	92.7	92.5	92.7	100.0	99.7
Total value added		799,074	96.4	94.2	96.8	96.2	94.0	93.0	93.3	92.7	94.0	93.2	100.0	100.1
Gross domestic output		1,520,518	96.3	94.0	96.7	96.3	93.8	93.2	92.6	92.3	93.7	92.7	100.3	100.5
Final demand		304,728	96.6	95.5	96.3	98.5	98.4	96.9	88.7	92.1	98.0	92.9	100.0	99.7
		1,000 jobs												
Employment, jobs		56,360	96.0	93.6	96.4	95.7	93.3	93.4	92.2	91.9	93.2	92.5	100.9	101.2

[1] This figure indicates that agriculture, forestry, and fisheries produced 97.2 percent of the base level production ($63,793), or $62,517 million worth of output.

was the source of initial problems with model solutions, described in (*15*)). Solution A also provides a reference base against which solution values for the restrictive simulations may be compared.

Reduction of Crude Petroleum Imports

Solutions B-1 and B-2 examine impacts of reductions in crude petroleum imports of 1.0 and 1.5 million barrels per day with GDO as the criterion function. The impact on output levels of the aggregated sectors from the 1.0 million barrels per day reduction ranges from the most severe decline of 7 percent for mining (which includes the crude petroleum sector through which the crude oil imports are handled by I/O accounting conventions) to the least severe decline of 3 percent for the agriculturally related sectors (table 3). (The "other" category, which includes dummy industries and imports, shows a slight increase because the dummy sectors use little energy and the negative trade balance of the base year is reduced due to the reduced level of energy importation).

Aggregate economic activity, as evidenced by changes in the indicators, is reduced approximately 4 percent overall. Notably, unemployment would increase 4 percent over the base (1967) level, GNP would decline 3.6 percent, and PCE and aggregate final demand would be reduced slightly over 3 percent.

The impacts of the 1.5 million barrel per day reduction are even more restrictive of economic activity, but similarly follow the patterns of the smaller reduction. As noted above, these simulations were similar to the stated energy policy goals of the administration. As such, they serve to demonstrate the complexity and relative magnitudes of the tradeoffs that must be considered when attempting (1) to stimulate a sagging economy with high unemployment on the one hand, and (2) to control inflationary pressures from costlier oil imports on the other. While all of the details of the current energy program being pursued are not reflected in this simulation, the results point up the apparent cross-purposes or conflicts inherent in the current situation and emphasize the roles of political and economic considerations.

Impact of Refined Petroleum Shortage

Solutions C-1 to C-3 and D-1 to D-4 examine impacts of a shortfall of 1 million barrels per day in refined petroleum supplies, accompanied by various possible allocation schemes which assume alternative societal objectives in allocation. Reduction in economic activity without allo-

Table 4.—Effects of simulations of alternative energy restrictions on final demand base for aggregated sectors, U.S. economy

Item	Sector Nos.	Final demand base	Simulation B-1	B-2	C-1	C-2	C-3
		Mil. dol.	*Percent*				
Sector:							
Agriculture, forestry, and fisheries	1-4	3,149	106.4	106.4	106.4	8.1	36.4
Mining	5-10	1,325	75.8	75.1	76.0	81.1	76.8
Construction	11-12	85,584	94.2	93.3	94.6	98.2	100.0
Manufacturing	13-64	123,386	93.5	92.4	94.1	98.4	95.0
Transportation and communication services	65-68	13,535	93.5	93.4	94.1	97.7	99.1
Trade	69	11,448	93.9	93.1	94.5	97.1	100.0
Finance, insurance, and real estate	70-71	4,138	100.0	100.0	100.0	100.0	100.0
Services	72,77	10,800	95.5	95.5	95.5	100.0	98.0
Other	78-87	53,203	105.4	107.1	101.7	101.7	103.7
Total final demand		304,728	96.6	95.6	96.3	98.5	98.4

Item	Sector Nos.	Final demand base	D-1	D-2	D-3	D-4	E-1	F-1	F-2
Sector:									
Agriculture, forestry, and fisheries	1-4	3,149	106.4	1.8	106.4	8.1	308.6	308.6	106.4
Mining	5-10	1,325	77.0	82.4	83.4	82.9	66.5	66.0	64.2
Construction	11-12	85,584	100.0	87.2	93.3	100.0	98.2	100.0	99;7
Manufacturing	13-64	123,386	95.0	89.8	83.9	95.2	98.6	99.3	80.7
Transportation and communication services	65-68	13,535	99.7	96.3	91.2	98.9	99.6	89.3	86.7
Trade	69	11,448	100.0	100.0	87.7	100.0	100.0	100.0	88.9
Finance, insurance, and real estate	70-71	4,138	100.0	100.0	100.0	100.0	36.8	13.3	100.0
Services	72-77	10,800	100.0	100.0	100.0	100.0	100.0	100.0	95.5
Other	78-87	53,203	90.7	101.9	104.0	102.2	95.9	94.5	108.6
Total final demand		304,728	96.9	88.7	92.1	98.0	100.0	99.7	92.9

cation (C-1) is most severe in the mining sectors, with a decrease of about 6 percent. The remaining sectors suffer reduction of smaller amounts; agriculture is affected the least with a reduction of less than 3 percent. Aggregate economic indicators also show reductions of about 3 percent. Notably, unemployment would increase almost 4 percent and GNP decrease about 3 percent from their 1967 base levels.

Some preliminary analysis suggested that allocation schemes (providing certain sectors enough fuel to fill their final demands) would affect sector production patterns. To examine allocation impacts, the refining sector was required to provide full base level usage (full final demand) to government services (solution C-2). As a second test, the agricultural production and related sectors (1-4) were allocated refined petroleum equal to their 1967 usage (solution C-3).

Both solutions with fuel allocation and a 7-percent shortfall in refined petroleum show that activity levels are altered by the allocation schemes. The ranking of sectors by severity of output reduction is considerably altered when the first allocation scheme is introduced, and even more so for the second. These results point up the well-known but sometimes overlooked consideration that providing a particular production sector with adequate quantities of one input is hardly helpful if necessary quantities of other inputs are unobtainable. Thus, while individual firm effects from a moderate fuel shortage may be significant, a longrun rationale for this allocation with this particular level of energy shortage may be more political than economic. In the shortrun, of course, institutional rigidities may provide an economic rationale. But in the longer run, interdependence between sectors is so great that the needed allocation for one sector depends heavily on the level of activity that is possible in the sectors directly bearing the shortfall in energy.

The level of agricultural production actually drops slightly when the relevant sectors receive favored treatment (C-3). This surprising result, on examination, occurs partly because of using the gross output objective function. Sector 3 (Forestry and Fishery Products) is a "net importer" of products in 1967, after PCE is made endogenous in the model. The inflow indicates net Federal Government sales (over purchases) of forest and fishery products (for example, timber from national forest land). If the objective is to maximize gross private output, this net inflow would not be used. Producing an equivalent amount in the private economy adds more to gross domestic output than would utilizing the limited fuel in other economic sectors. This finding is consistent with the model formulation, but suggests that alternate objective functions may provide results to be preferred.

Refined Petroleum Restriction, Alternative Objective Functions

What effect does the choice of a national objective have on optimal fuel allocations? In addition to the solution series maximizing GDO, 4 alternative objective functions were examined using the 7-percent refined petroleum shortage with allocation to government and agriculture, described above. (Thus, the D-series solutions can be compared with solution C-3). The alternative objectives maximized were numbers of workers in private employment (EMPL), IBT, PTI, and TVA. IBT and PTI are components of TVA, along with EC. These objectives reasonably approximate a variety of interests affected by an energy shortage: employment, net production, part of government tax revenues, and capital earnings.

Three of the four alternate objective functions yielded similar solution patterns to those from the GDO function. The solution maximizing employment, D-1, shows considerable variation in pattern from the others. For this level of energy reduction, the aggregate indicators show only slight variation for the GNP-related objectives, but the aggregated sectors exhibit significant variation in relative output levels. For example, PCE varies from 94.1 percent of base for IBT to 91.4 percent for TVA while the construction sector varies from 88.2 to 98.7 percent for the same objective functions. Solutions maximizing TVA and GDO are very similar, as would be expected, since there is generally high correlation between gross output and value added for most sectors. (There are important exceptions, however).

Using employment as the criterion function produces some differences from other solutions even for this level of energy constraint. The tendency, of course, is to encourage increased production levels in the relatively labor intensive industries such as manufacturing. While the aggregate indicators shift little, aggregate employment is increased slightly over the solution using the alternative objectives. Thus, there does appear to be a sort of Phillips curve tradeoff available to persons dealing with restraining gasoline consumption. There are some more subtle effects to objective function choice which may not be initially evident, however. For example, maximizing employment puts the most people to work but it also produces the lowest level of PCE of all the objectives. This would suggest that the marginal jobs created by pursuing this objective are likely to be in relatively low wage industries, producing employment income which adds little to aggregate PCE, and hence, aggregate economic activity.

The rationale for choice of an objective function is nebulous at best. We do not have one national goal, but many (for example, see (*3*, *19*)), and these goals are not always consistent; some conflict severely. Thus, it is somewhat unrealistic to assume an overriding goal of maximizing gross output, or employment, or GNP, as tradeoffs will always exist among national goals. However, the information obtained from alternative solutions with a single objective may provide additional information to policymakers on the kinds and magnitudes of these tradeoffs as there do appear to be important differences in results depending upon choice of objective. Another approach, discussed below, is simultaneous consideration of several objectives through use of multiple-goal objective functions.

Natural Gas Restriction

The impacts on the total economy resulting from a 10-percent natural gas shortage with no allocations (solution E-1) are reductions of about 7 percent in the aggregate indicators. PCE is reduced about 6 percent; IBT and PTI about 7 percent; TVA, GDO, and aggregate final demand about 7 percent; and employment is reduced 7.5 percent (4.2 million workers). Aggregate output effects are less than proportionate to the fuel restriction because intermediate product demands at all levels are lessened as the economy cuts back.

The reduction in output varies across aggregated sectors. Mining is the most seriously affected, showing an approximately 11 percent decline, primarily in chemical and fertilizer mineral mining (sector 10), a sector heavily dependent upon natural gas. The 4 agricultural production sectors show a combined reduction of less than 5 percent. The reduction in output for the other sectors varies from less than 2 to 10 percent (ignoring the "other" grouping).

Expanding Agricultural Exports

Since 1973, U.S. agricultural exports have greatly expanded. Demands of the export market have caused farmers to increase agricultural output to record levels. One argument of proponents of policies for maintaining production for export at high levels is that large exports are one way of obtaining foreign exchange to offset massive outflows caused by the rise in world oil prices. Other proponents argue that large amounts of food will be needed to meet growing food deficits in the developing countries. Does the current energy situation create a need for special allocation schemes to encourage production of agricultural products for export?

The 1967 level of commodity exports was tripled to reflect the approximate 1973-74 levels (solutions F-1 and F-2). This was introduced into the model by increasing the final demand (RHS) level of sector 2, the major agricultural crop producing sector consisting of food and feed grains and soybeans.

The first simulation (F-1) utilized the 1967 base energy levels, to see where curtailments would occur. The second (F-2) was obtained with the energy rows "free" (that is, unconstraining, acting as accounting rows) to obtain energy totals that are required for this additional activity.

With 1967 fuel supplies, the agricultural sectors show a 12-percent increase in production over the equilibrium level, 4 other sector groupings show slight reduction, and the remainder meet or exceed equilibrium levels. For the unconstrained energy solution, there is little change in sector activity levels. The agricultural sectors' output level increases only slightly, indicating that the increased demand was almost met in the previous solution. The aggregate indicators show the result of increased trade on the overall economy; for example, PCE, GNP, and GDO up slightly, employment up 1.2 percent, and so forth. Comparison of these results suggests the relative ease with which the economy could provide fuel necessary for moderate expansion of food and fiber production.

Impacts on a Food and Fiber System

No particular I/O representation of a food and fiber sector is acceptable for all purposes. Several have been devised, and each representation is usually particular to its use. At the 85-sector tableau level, the sectors are too gross to permit more than a crude specification. Several of the 9 aggregate sectors used in tables 3 and 4 contain components of a food and fiber system. One possible specification, a food and fiber system composed of 19 sectors from the 85-sector tableau, is shown in tables 5 and 6. Gross income and employment totals shown exclude transportation and trade because, at this level of aggregation, food and fiber proportions of these sectors are small.

Individual sector results from three of the previously discussed simulations, B-1, C-1, and E-1, are generally consistent with the aggregate results discussed above. But the impacts of the various restrictions and allocations may be more clearly seen with this level of detail. This type of information is of interest to agricultural specialists.

For the three illustrative energy reductions, impacts varied considerably by sector. The five designated input sectors reduced output over a wide range. The chemical and fertilizer sectors are most affected, being large users of direct energy forms. The farm machinery manufacturing sector (44) is little affected by the reductions. Sales from sector 68, which contains gas utilities through which the 10-percent natural gas reduction is implemented, are reduced approximately 10 percent.

Three of the four agricultural-related sectors (1, 2, and 4) show output reductions, the most serious for natural gas. Sector 3, forestry and fishery products, shows an increase of 4 to 7 percent. The explanation for this apparently perverse result is the use of the gross output maximizing function which favors sector production over use of the capital inflow, as discussed earlier.

Output impacts on the 10 sectors designated as processing and distribution sectors are also varied. The most severe curtailments also result from the natural gas shortage. Eight sectors, including the relatively large food and kindred product processing sector (14), are reduced, from about 3 to 10 percent. The textile-related sectors (16 and

Table 5.—Impact of simulations of alternative energy restrictions on gross output base of sectors representing a food and fiber system

Item	Sector No.	Gross output base	Simulation[1] B-1	C-1	E-1
		Mil. dol.	*Percent*		
Food and fiber system					
Input sectors:					
Chemical and fertilizer mining	10	1,027	94.5	95.0	83.9
Chemicals and selected products	27	23,182	93.0	93.7	77.2
Petroleum refining and related industries	31	26,975	94.8	95.3	93.1
Farm machinery	44	4,826	99.7	99.7	99.1
Electricity, gas, water, and sanitary services	68	37,321	95.3	95.7	90.3
Production sectors:					
Livestock and livestock products	1	30,638	96.8	97.1	94.0
Other agricultural products	2	28,540	97.0	97.3	94.5
Forestry and fishery products	3	1,945	106.7	107.0	104.3
Agriculture, forestry, and fishery services	4	2,670	97.1	97.4	94.8
Processing and distribution sectors:					
Food and kindred product processing	14	89,451	96.8	97.1	93.9
Tobacco manufacturing	15	7,940	97.2	97.5	94.6
Broad and narrow yarn fabrics, and yarn and thread mills	16	15,966	92.8	93.1	90.0
Miscellaneous textile goods and floor covering	17	4,668	96.1	96.3	93.3
Apparel	18	22,566	96.8	97.1	93.9
Miscellaneous fabricated textile products	19	4,283	97.2	97.5	94.6
Lumber and wood products	20	12,905	96.6	96.8	96.5
Wooden containers	21	542	97.0	97.2	93.9
Transportation and warehousing	65	52,825	95.7	96.1	91.9
Wholesale and retail trade	69	163,365	96.3	96.4	93.2
Gross income[2]		315,445	96.1	96.4	92.3
Employment (1,000 jobs)[2]		10,630	96.4	96.7	93.1

[1] Solutions maximizing gross domestic output. [2] Sectors 65 and 69 are excluded.

Table 6.—Impact of simulations of alternative energy restrictions on final demand base of sectors representing a food and fiber system

Item	Sector No.	Final demand base	Simulation B-1	Simulation C-1	Simulation E-1	Shadow prices Inter-mediate demand	Shadow prices Final demand
		Mil. dol.	*Percent*			*Dollars*	
Food and fiber system							
Input sectors:							
Chemical and fertilizer mining	10	187	100.0	100.0	100.0	3.59	3.22
Chemicals and selected production	27	3,880	86.3	88.4	33.2	.37	0
Petroleum refining and related industry	31	2,676	86.2	87.2	100.0	.37	0
Farm machinery	44	3,829	100.0	100.0	100.0	1.25	.89
Electricity, gas, water, and sanitary services	68	2,017	84.4	85.5	62.3	.66	0
Production:							
Livestock and livestock production	1	207	100.0	100.0	100.0	1.47	1.11
Other agricultural products	2	2,093	100.0	100.0	100.0	.98	.61
Forestry and fishery products	3	200	0.0	0.0	0.0	1.20	0
Agriculture, forestry, and fishery services	4	49	100.0	100.0	100.0	1.48	1.12
Processing and distribution:							
Food and kindred product processing	14	3,937	100.0	100.0	100.0	1.76	1.39
Tobacco manufacturing	15	789	100.0	100.0	100.0	1.47	1.10
Broad and narrow yarn fabrics, and yarn and thread mills	16	465	0.0	0.0	0.0	-.60	0
Miscellaneous textile goods and floor covering	17	305	100.0	100.0	100.0	.87	.50
Apparel	18	621	100.0	100.0	100.0	.89	.53
Miscellaneous fabricated textile production	19	476	100.0	100.0	100.0	.87	.50
Lumber and wood products	20	529	100.0	100.0	100.0	.92	.55
Wooden containers	21	30	100.0	100.0	100.0	1.19	.82
Transportation and warehousing	65	9,257	93.9	94.5	88.9	.96	0
Wholesale and retail trade	69	11,448	93.9	94.5	88.9	.59	0
Final demand[3]		22,890	93.5	94.1	84.2		

[1] Solutions maximizing gross domestic output. [2] Shadow prices are from Solution B-1. [3] Sectors 65 and 69 are excluded.

18) are generally cut most severely.[8] For sector 16, the fabric, yarn, and thread mills, the reduced output ranges from approximately 10 percent for the natural gas shortage to 7 percent for the crude petroleum reduction. The miscellaneous textile goods and floor covering sector (17) is similarly affected with reductions of 4 to 7 percent.

The transportation and warehousing sector is reduced up to 8 percent and trade to almost 7 percent, both extremes occurring under the naural gas reduction. Gross income (sales) to the system is reduced from almost 4 to 8 percent for the simulations. The system as defined has a base level employent of 10.6 million and these restrictions cause reductions of from 3 to 7 percent.

[8]The model probably underestimates the impact. The I/O coefficient is based on 1967 equilibrium flows between sectors, and the indicated cutback would occur with no allocations in effect. As a matter of fact, however, there would be both geographic and allocation restrictions. These sectors are concentrated in the Southeastern United States and are heavily dependent upon natural gas for production. Also, their supply is generally tenuous, many plants being in the "first interruptable" category when shortage occurs.

To provide additional detail on impact of choice of objective function, the solutions for the five alternative functions are also presented for the food and fiber system representation, but are only briefly discussed (tables 7 and 8). Using employment as the criterion function most nearly maintains their output. This result is not surprising since most of the industries included are relatively labor intensive. Gross income varies little for the alternative functions but the sector impacts show more variation. For example, food and kindred product processing, one of the largest sectors in the system, varies from 94.2 percent to 91.7 percent of base, depending upon whether GDO or IBT is maximized.

The choice of criterion function is also significant in determining shortages in the final demand market. Final demands for the various sectors are restricted differently. In any shortage, some final demands must go unmet. Which ones depend on the type of shortage, its severity, and the objective being optimized. The patterns of final demands met are seen to vary considerably across the sector (table 8). Final demands to most sectors and for the aggregate are most severely undermet when IBT is the cri-

Table 7.—Impact of simulations of alternative energy restrictions on gross output, food and fiber system

Sector	Sector No.	Base	Simulation				
			C-3	D-1	D-2	D-3	D-4
		Mil. dol.			*Percent*		
Food and fiber system							
Inputs:							
Chemical and fertilizer mining	10	1,027	80.9	81.5	79.6	81.2	81.0
Chemicals and selected products	27	23,182	71.4	72.0	69.9	71.8	71.5
Petroleum refining and related industries	31	26,975	91.7	91.7	91.7	91.7	91.7
Farm machinery	44	4,826	98.7	99.2	98.4	99.2	98.4
Electricity, gas, water, and sanitary services	68	37,321	91.8	91.7	91.6	91.8	91.8
Production:							
Livestock and livestock products	1	30,638	91.4	91.4	93.4	93.3	91.4
Other agricultural products	2	28,540	84.5	92.3	82.8	93.9	81.3
Forestry and fishery products	3	1,945	104.0	103.6	88.4	104.2	104.1
Agriculture, forestry, and fishery services	4	2,670	88.9	92.8	87.8	94.1	87.4
Processing and distribution:							
Food and kindred product processing	14	89,451	91.7	91.2	94.2	93.2	92.0
Tobacco manufacturing	15	7,940	92.5	92.0	94.7	94.0	92.6
Broad and narrow yarn fabrics, and yarn and thread mills	16	15,966	88.8	90.0	85.5	89.8	88.6
Miscellaneous textile goods and floor covering	17	4,668	93.1	93.0	84.9	94.0	93.2
Apparel	18	22,566	91.7	91.1	90.6	93.2	91.9
Miscellaneous fabricated textile products	19	4,283	93.0	92.7	82.9	94.2	93.1
Lumber and wood products	20	12,905	97.2	97.1	85.4	96.0	97.2
Wooden containers	21	542	92.2	93.7	91.3	93.7	91.7
Transportation and warehousing	65	52,825	94.2	94.1	93.7	92.0	94.2
Wholesale and retail trade	69	163,365	89.8	90.4	89.4	91.5	89.6
Gross income[1]		315,445	89.8	90.4	89.4	91.5	89.6
Employment (1,000 jobs)[2]		10,630	89.6	91.6	78.9	92.4	90.6

[1] Sectors 65 and 69 are excluded.

terion function. The reader should recall that final demand in this model includes gross private capital formation, export, and Government uses. Domestic consumption (PCE) is not included in final demand as it is treated as endogenous to the model—as an intermediate product.

For the situations examined, the food and fiber system would be more severely affected than the economy as a whole. Employment declines would be greater (78.9 percent versus 91.9 percent of base) and gross income declines would show even greater disparity. These simulations reinforce the well-known overall conclusion that, given emergence of specific shortages, alternate schemes to alleviate their impact may produce similar results for the economy in the aggregate, but the impacts on individual sectors may be markedly different. For the selected sectors shown, the results further emphasize the direction and relative magnitudes of tradeoffs that should be considered by policymakers in selecting one or more economic goals for emphasis over others.

Shadow Prices

Another useful output from the model is the shadow price or dual multipliers.[9] These, of course, indicate the values of additional units of the limited resource, or, in I/O, of increased final demand levels. For energy, they could be particularly useful in deriving an allocation scheme of limited fuels to various uses, one which would be consistent with a specified national objective, such as maximizing employment or GNP. These values often are highly specific to the type of energy shortage and the type of allocation scheme assumed.

The model is formulated in such a way as to separate impacts of various energy forces on shadow prices. Energy import availability is separated from domestic production to isolate effects of the domestic production

[9] See (*18*) for a discussion of shadow price interpretation for constrained I/O models as well as a shortcut procedure for estimating such prices.

Table 8.—Impact of simulations of alternative energy restrictions on final demand, food and fiber system

Sector	Sector No.	Base	Simulation				
			C-3	D-1	D-2	D-3	D-4
		Mil. dol.	*Percent*				
Food and fiber system							
Inputs:							
Chemical and fertilizer mining	10	187	100.0	100.0	100.0	100.0	100.0
Chemicals and selected products	27	3,880	0	0	0	0	0
Petroleum refining and related industries	31	2,676	100.0	100.0	100.0	100.0	100.0
Farm machinery	44	3,829	100.0	100.0	100.0	100.0	100.0
Electricity, gas, water, and sanitary services	68	2,017	93.9	98.0	75.5	88.1	92.5
Production:							
Livestock and livestock products	1	207	100.0	100.0	100.0	100.0	100.0
Other agricultural products	2	3,093	28.8	100.0	0	100.0	0
Forestry and fishery products	3	-200	0	0	100.0	0	0
Agricultural, forestry, and fishery services	4	49	100.0	100.0	100.0	100.0	100.0
Processing and distribution:							
Food and kindred product processing	14	3,937	100.0	100.0	100.0	100.0	100.0
Tobacco manufacturing	15	789	100.0	100.0	100.0	100.0	100.0
Broad and narrow yarn fabrics, and yarn and thread mills	16	465	0	38.5	0	0	0
Miscellaneous textile goods and floor covering	17	305	100.0	100.0	0	100.0	100.0
Apparel	18	621	100.0	100.0	0	100.0	100.0
Miscellaneous fabricated textile products	19	476	100.0	100.0	0	100.0	100.0
Lumber and wood products	20	529	100.0	100.0	0	100.0	100.0
Wooden containers	21	30	100.0	100.0	100.0	100.0	100.0
Transportation and warehousing	65	9,257	100.0	100.0	100.0	89.7	100.0
Wholesale and retail trade	69	11,448	100.0	100.0	100.0	89.7	100.0
Total final demand		22,890	71.7	82.3	56.9	80.8	67.7

sectors. Domestic consumption is made a function of endogenously determined wage earnings plus a constant for nonwage income of persons. The model determines which of the final demands go unmet in a shortage situation, and hence assigns shadow values to increased imports, decreased final demands, and capacities. By the formulation of equation sets (1) and (2), values originating in final demand can be separated from those originating in intermediate product uses.

To illustrate the type of information provided by the shadow prices in this context, the shadow prices on constraints (1) and (2) from the 1.0 million barrels per day crude petroleum shortage simulation for the food and fiber system are shown in table 6. The shadow prices on constraint (1) indicate the effect of a change in the requirement that output equal demand. These shadow prices are the well-known Leontief output multipliers, if only constraints (1) and (2) are binding. However, when other constraints are binding, the observed effect is that some of final demand is unmet. Then, the shadow prices of constraints (2) and (3) take the following interpretations (*12*): If both (2) and (3) are binding, the shadow prices indicate the same information as the output multiplier; that is, the change in the objective function for a unit change in final demand. For example, the shadow prices for sector 10 for intermediate and final demand are \$3.59 and \$3.22, respectively, and they are interpreted as the increment to the objective function for an additional \$1 final demand for chemical and fertilizer mineral mining. If (1) is binding and Y is at a nonzero level, final demand has been saturated; the shadow price on (1) indicates the value of another unit of intermediate demand and the shadow price on (2) is zero. This case is illustrated by sector 27, chemicals and selected products. If (1) is binding and Y is zero, final demand is not accepted at all and the shadow price on (1) becomes the cost of having to meet all domestic demand (sector 16, for example).

Since crude petroleum is the limiting energy source in this simulation (B-1), the shadow price is from constraint (6), and in this case is \$30, indicating the value of an additional 1 million BTU's of crude petroleum. For reference, the present crude import price is about \$10.25 per barrel containing 5.8 million BTU's, or \$1.77 per million BTU's. The \$30 price indicates an imported value per barrel of \$174 to the total economy.

MODEL CREDIBILITY, LIMITATIONS, AND EXTENSIONS

Credibility

The usefulness of simulations from models such as these for policy prescription, evaluation, or other purposes depends, of course, upon the validity of the results. A widely used validation or evaluation procedure is comparison of model results with comparable historical data and analysis of the discrepancies. This procedure has only limited applicability here due to the nature of the model and the problem. One assessment that lends prerequisite credibility is that we could reproduce the 1967 economy exactly, confirming that the structure is correct and the data correctly entered. Our examination also suggested that the results are consistent with the expected model performance. Since these data pertain to the 1967 base, entering the final demands for 1976 into the model and comparing the solution results with consistent USDC published data would provide some insights into how much the structure of the economy may have changed in the ensuing years. However, for large changes, one cannot really tell what combinations of technical coefficient changes are responsible for discrepancies.

Limitations

Results available from the model must be viewed in light of a combination of the separate assumptions employed both in LP and construction of the I/O tableau. Some of the more important assumptions present in the formulation described are only briefly noted below (see (*1*, *4*, *11*) for a more detailed treatment).

- Each commodity is produced by a single sector (industry). Current data on allocations of final demand to I/O sectors are not generally available, except by bridging between 1967 I/O tables and national income data.
- The I/O formulation in general does not allow substitution. Our formulation permits the "substitution" in the sense of underproducing for final demand, but the major component, PCE, is internalized in this formulation.
- The inputs used by a sector are a linear homogenous function of the activity level of that sector (proportionality). Simulations of major changes may strain this assumption.
- Internal economies and diseconomies are absent (additivity).
- All relations are nonstochastic and continuous.
- Technology is fixed and dated—1967 I/O and energy data are used, which implies production under 1967 technology and price levels. More recent data are unavailable in this form.
- An implication is that the economy is assumed not to have alternative production techniques which might be less energy intensive, allow substitution of one fuel type for another, or permit substitution of labor for energy. At best, this assumption is valid only in the short run. Also, the realism of the model relative to current conditions is lessened because of the changes in relati^ve input (especially petroleum) and product prices since 1967.[10]

Extensions

Many additional extensions could be made of the basic model. Modifications and extensions suggested below would enhance the capability of the model for providing additional detail, broaden the range of questions which might be addressed, and add realism or closer correspondence to current economic and energy conditions:

- Use of the existing model with final demands data for later years is possible. This would involve replacement of the "household" sector (row 88-EC and column 88-PCE) and the remainder of final demands in the RHS with the more current data.
- Additional detail for the various sectors can be provided by using the 1967 USDC 367-sector I/O tableau. This would permit specification of a food and fiber system of over 65 sectors.
- A different kind of improvement in detail would result from further breakout of the energy resources into component products, especially such critical ones as motor gasoline, aviation fuel, diesel fuel, home heating oil, or grades of coal.
- Introduction of alternative production technologies into the model is another possible extension. For example, instead of a single sector representing commodity production, several sectors representing alternative methods for producing that commodity could be introduced to allow systematic choice by the model, ensuring that the final result would be optimum for the given conditions.[11]
- Another improvement in the model would, of course, be to obtain more current I/O, energy utilization, and employment data. However, an updated I/O tableau from USDC is still some years away.[12]
- Multiple objective programming, also known as "goal programming" (*9*), basically involves setting goals (for example, 6 percent unemployment, a specific level of GNP, a 5-percent reduction in energy utilization, and so forth), then optimizing over the deviations from these goals. Such an analysis would appear to provide highly useful information to policymakers for analyses associated with the continuing energy situation.
- A further extension of this model is the incorporation of a price-quantity response system via quadratic pro-

---

[10]The USDC now prepares an I/O table following each quinquennial census of business. The most recently available table, for 1967, was released on computer tape in late summer 1974.

[11]A small model of tobacco production reported by Mann (*10*) is illustrative.

[12]See (*21*, *22*) for a discussion of procedures for updating model coefficients. The Bureau of Labor Statistics has projected an 90-odd sector tableau for 1970 based upon the 1963 tableau and has projected a capital coefficients matrix to 1970 based upon the 1958 version.

gramming. Harrington (*5*) has shown how models such as this can be formulated with price-responsive primary resources and final demands. For the current model, this reformulation would incorporate price-responsive energy supplies and price response to export products. Also, using the Duloy-Norton approach (*2*), a linear programming specification of the problem could be made.

- Other interesting extensions and modifications could be suggested, but those listed illustrate the potential versatility of the model.

CONCLUSIONS

The growing interdependence among the sectors of the domestic economy and of the U.S. economy with those of other nations of the world mandate that economic analyses incorporate more of this interdependence than previously has occurred. The growing domestic interdependence among economic sectors is exemplified by the energy situation. Our primary emphasis was to develop an analysis of impacts on the food and fiber system of alternative energy situations in the context of the total economic setting.

Results of the illustrative simulations suggested that the indirect or "hidden" consequences of certain shortages and allocation schemes are significant and may be different than might be expected. The tradeoffs from emphasizing specific economic goals may be traced through and also provide insights into possibly unexpected, indirect effects of shortages and policies to cope with them.

Individual sector results, for sectors selected to crudely represent a food and fiber system, suggest that fuel allocations to agricultural production may be of little assistance if other needed inputs are unobtainable. The results further suggest that, of input industries, the fertilizer and chemicals sectors are relatively more severely affected by the shortages than others. Food processing is also a potential bottleneck, especially in specific product sectors, but the 85-sector I/O tableau is too aggregated to explore this further. The agricultural production sectors are not more severely affected relative to many others, and specific allocations of full fuel needs appear to have little impact unless other input supplying industries are also able to make inputs available. Energy constraints on processing, transportation, and distribution sectors could still curtail the supplies of food and fiber reaching consumers. This is evidenced by the severity of impacts of the fuel shortages treated here on the textile-related sectors.

Overall, we conclude that accounting for sectoral interdependence enhances our analyses of the recent resources shortages and that, even with the inherent limiting assumptions and dated base data, constrained I/O models provide additional information and flexibility for consideration in policy analyses. Numerous extensions and refinements would further enhance their usefulness.

REFERENCES

(1) Chenery, Hollis B. and Paul G. Clark. *Interindustry Economics*. New York: Wiley and Sons, Inc., 1959.

(2) Duloy, John H. and Roger D. Norton. "Prices and Incomes in Linear Programming Models." Discussion paper No. 3., Development Res. Ctr., Internatl. Bank for Reconstruction and Development, November 1974.

(3) *Economic Report of the President*. Washington: U.S. Govt. Print. Off., February 1975.

(4) Hadley, G. *Linear Programming*. Reading: Addison-Wesley, Inc., 1962.

(5) Harrington, David H. "Quadratic Input-Output Analysis: Methodology for Empirical General Equilibrium Models." Ph.D. Thesis, Purdue Univ., 1973.

(6) Herendeen, Robert A. *The Energy Cost of Goods and Services*. ORNL, NSF, EP-58, Oak Ridge, Tenn., October 1973.

(7) Irwin, G. D., and J. B. Penn. "Energy, Government Policies, and the Structure of the Food and Fiber System." *Am. J. Agr. Econ.*, 57 (1975):829-35.

(8) Kendrick, John W. *Economic Accounts and Their Uses*. New York: MGraw-Hill, 1972.

(9) Lee, S. M. *Goal Programming for Decision Analysis*. Philadelphia: Auerbach, 1972.

(10) Mann, J. S. "Input-Output Models and Technical Change: Some Explorations in Methodology." *Agr. Econ. Res.*. 27 (1975): 1-8.

(11) Miernyk, William H. *The Elements of Input-Output Analysis*. New York: Random House, Inc., 1965.

(12) McCarl, B. A., J. B. Penn, G. D. Irwin, and L. Brink. "Simulations of the National Economy with Alternative Energy Availabilities." Paper presented at the AAEA annual meetings. Columbus, Ohio, August 1975.

(13) McCarl, B. A. and Hal Everett. "Regional Economic Planning: A Methodology for Integrating Linear Programming and Input-Output Analysis." Journal paper 5798, Purdue Agr. Expt. Sta., 1975.

(14) Penn, J. B., B. A. McCarl, O. C. Doering, and L. Brink. "Structural Input-Output Modeling of the Food and Fiber System Under Conditions of Fuel Scarcity." Paper presented at the AAEA annual meetings. College Station, Tex., August 1974.

(15) Penn, J. B., G. D. Irwin, and B. A. McCarl. "Adapting the National Input-Output Tableau into a Constrained Optimization Framework for Analyzing Energy Utilization." Paper presented at the AAEA annual meetings. Columbus, Ohio, August 1975.

(16) Penn, J. B., B. A. McCarl, L. Brink, and G. D. Irwin. "Modeling and Simulation of the U.S. Economy with Alternative Energy Availabilities." *Am. J. Agr. Econ.*, 58 (1976): 663-671

(17) Schluter, Gerald E. and Eldon Weeks. "A Programmed I/O Model for Valuing Constraints." Unpubl. paper, Econ. Res. Serv., U.S. Dept. Agr., 1974.

(18) Schluter, Gerald and David Dyer. "The Economic Interpretation of Constrained Input-Output Solutions." *Rev. Econ. and Statist.*, 58 (1976): 245-248.

(19) Simon, William E. "Statement of the Secretary of the Treasury Before the Subcommittee on Priorities and Economy in Government of the Joint Economic Committee." Washington, D.C., Apr. 3, 1975.

(20) Simpson, D. and D. Smith. "Direct Energy Use in the U.S. Economy, 1967." Ctr. for Advanced Computation, Tech. Memor. 39, Univ. Ill., January 1975.

(21) U.S. Department of Commerce, Interindustry Economics Division. "The Input-Output Structure of the U.S. Economy: 1967." *Surv. Current Business*, 54 (1974):24-56.

(22) U.S. Department of Labor, Bureau of Labor Statistics. *Projections 1970 Interindustry Relationships Potential Demand Employment*. Bul. 1536, Washington: U.S. Govt. Print. Office, 1966.